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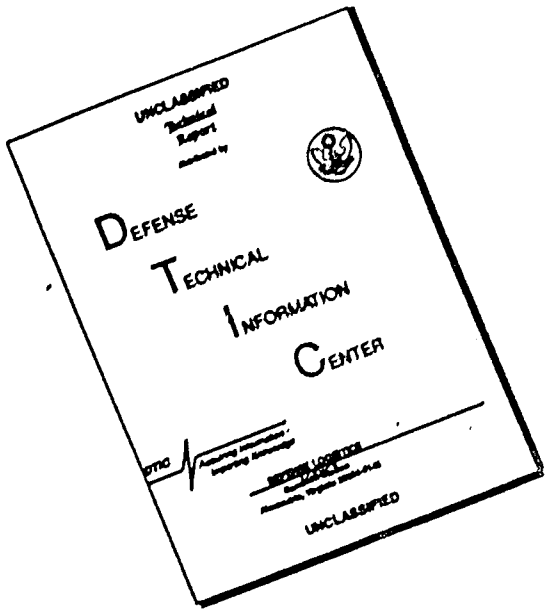

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BRAIN AND MUSCLE ACTIVITY DURING MUSCULAR WORK

- USSR -

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BRAIN AND MUSCLE ACTIVITY DURING MUSCULAR WORK

- USSR -

/Following is the translation of two articles from the Russian-language publication Doklady Akademii Nauk SSR (Reports of the Academy of Sciences USSR), Vol 146, No 3, 1962. Additional bibliographic data accompanies each article./

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GASEOUS METABOLISM AND BIOELECTRIC ACTIVITY OF THE BRAIN AND MUSCLES OF MAN DURING MUSCULAR WORK, AS AFFECTED BY TEMPERATURE

/Following is the translation of an article by L. A. Isaakyan, R. P. Ol'nyanskaya, and G. A. Trubitsyna in the Russian language publication Doklady Akademii Nauk SSSR (Reports of the Academy of Sciences USSR), Vol 146, No 3, 1962, pages 728-730/

(Presented by the Academician V. N. Chernigovskiy, 5 April 1962)

The effect on the organism of the temperature factor of the immediate environment during muscular work is of great interest, since heat control functions not only at rest, but also during various forms of muscular activity. Muscular work, in essence, is one of the factors of heat control. The literature data on this problem, obtained from observations on man, are very contradictory and insufficient to establish their nature and causes for changes in heat exchange during muscular work. The central and peripheral mechanisms of heat control in the organism during muscular work have been left entirely uninvestigated. In the present study, the investigation of the bioelectric activity of the muscles and brain makes possible an explanation of the participation of the muscular system and the central nervous apparatus in the control of heat formation during the period of work. Our observations were conducted on five healthy adults, ranging in age from 20 to 25. Determination of gaseous metabolism was carried out by means of the Belau electrical automatic instrument. At the same time the currents of muscular action (forearm flexor) and the bioelectrical activity of the brain (measurement of the α-rhythm) were recorded on an oscillograph. Included in the oscillograph circuitry were filters and integrators, the leads of which were connected to electromechanical counters, automatically recording the activity of the brain and muscles. Cooling or warming of the arm was accomplished by use of rubber bladders, filled either with ice or water of the appropriate temperature (0-2 or 45°). The persons investigated were placed in a partitioned chamber at an air temperature of 22-24°.

The analysis of experimental material showed that during a three-minute session of muscular work (raising a dumbbell held in the right hand upon a spoken signal) a substantial increase in gaseous metabolism took place -- averaging 25-52% of the original level. After five minutes upon completion of the work gaseous metabolism did not reach the original values for all the persons studied. These changes in muscular metabolism were accompanied by an increase in the currents of muscle activity during the muscular work period and by the appearance of a suppression reaction of the α-rhythm on the encephalogram (Figure 1B). For only one warming of the arm gaseous metabolism did not change or decreased somewhat, nor did the electrical potentials of the muscle vary. The suppression of the α-rhythm appeared after a one-minute activity of the irritant. The chilling employed resulted in an increase of gaseous metabolism (of 15-20%) that was somewhat less than during the muscular load. Following cooling, gaseous metabolism was restored after one minute. The suppression of α-rhythm was similar to that during the work session, but the shifts were less pronounced in value and in time. Cooling the arm was not always accompanied by an increase in the potentials of the resting muscle. But in some of the persons investigated, under the conditions of our observation, it was possible to observe an intensifying of the bioelectric activity of the muscle during rest and during cooling (the so-called heat controlling tonus). These data agree with the observations of Göpfert and Stufler (1), who during the total cooling of the individual in the chamber recorded the appearance of tonic stress in the maximally weakened muscles of the extremities and the trunk, but did not discover a definite relationship between changes in muscular activity and metabolism. Also supporting the absence of well-defined shifts in heat production and muscular activity are the studies of Davis (2) dealing with an explanation of the mechanism of the cold acclimatization of man.

If the muscular work is preceded by a two-five-minute cooling of the arm, then the energy expenditure of the work is decreased (Figure 1C) or remains unchanged; the restorative period following the work is also shortened. Consequently, preliminary cooling did not result in an increase in the work shifts of gaseous metabolism as would be expected, inasmuch as it is generally known that cold stimulates the mechanisms of chemical heat control. This can be seen in the changes of the electric indices of the muscles and the brain (Figure 1C). Following cooling the total (integrated) electric activity of the working muscles decreases an average of 14-43% depending on the length of the preliminary cold treatment. The suppression of the α-rhythm during a work period under these conditions can be less pronounced compared to the control studies without cooling. A direct relationship between the changes in metabolism and the electrical activity of the muscles is far from a regular occurrence. Thus, in the presence of a "heat-controlling tonus", when the biopotentials of the muscles are increased during cooling in

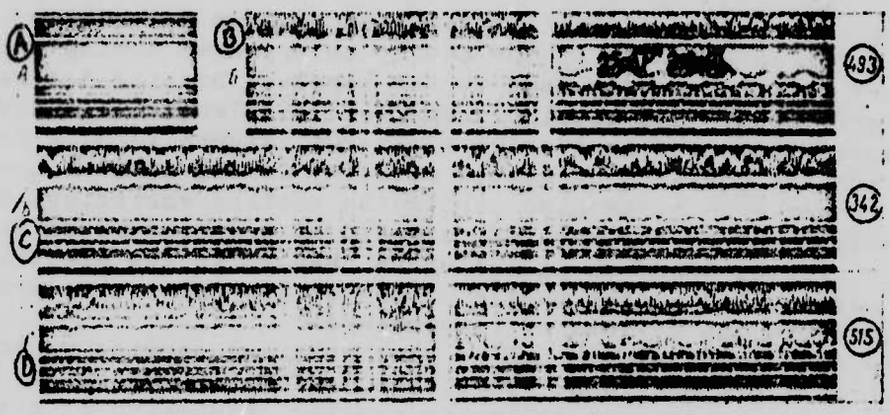

Figure 1. Change in gaseous metabolism and bioelectric activity of the brain and muscles during muscular work of patient K. A - amplifier noise; B - during muscular work; C - same as B but following preliminary three-minute cooling of arm; D - same as B but after preliminary three-minute warming of arm. Left-hand areas for B, C, and D -- in resting state; right-hand -- during work period. On kymograms top to bottom: electroencephalogram (occipital connection), α-rhythm, electromyogram, integrator mark, pulse, time mark (1/10 second). Calibration for the electroencephalogram identical for all series of experiments both at rest as well as during muscular work. For the muscles the calibration for all series of experiments is given during the work period, but during rest the amplification is reduced to a tenth. Circled figures represent excess need of oxygen (in milliliters) during the work period.

a resting condition, the electrical activity of the muscle is also somewhat increased during the period of its subsequent work, but in this connection an increase of work metabolism does not occur. Evidently, during muscular activity it is difficult to estimate its participation, based on electrical indices of muscles, in the chemical heat control processes. It is possible that during the work period under definite conditions chemical heat control does not appear, but the heat forming during the lengthwise contraction of muscles can be utilized to sustain the heat balance in the organism during cooling. In other words, the changes in heat production caused by the external temperature can be covered by the work shifts of metabolism and this stems from the savings of energy expenditure for the purpose of sustaining homeostasis.

If muscular activity occurs subsequently to a warming of the arm, then both the work shift of gaseous metabolism as well as the course of their restoration are almost indistinguished from the given control studies without the play of temperature (Figure 1*D*).

In several experiments a small increase in gaseous metabolism occurred. The suppression of the α-rhythm appeared during a one-minute work session and for most of the persons investigated was very insignificant. The total (integrated) bioelectrical activity of the muscle increased an average of 15-20% (Figure 1*D*) in comparison with the currents of muscle activity during work without warming. However here, as also during the cooling variation, we can scarcely speak of the physical effects of temperature on the activity currents, inasmuch as analogous changes in the electrical activity occurs also in the muscle of the other, nonworking arm, not subjected to the effects of temperature.

The experimental material we have obtained permits us to express several propositions. Thus, the differences observed during the period of muscular work following cooling or warming of the arm can, evidently, be explained by the physiological significance of the stimuli used. During warming, the external heat combines with the heat formed during the work period and disturbs the state of homeostasis. The body temperature is increased, heat exchange is complicated, and the conditions of work are worsened. Apparently, warming signalizes the "severity" of the work, and as a result an increase in the energy outlay and the biocurrents of muscle can be observed. Completely opposite changes result from cooling, which improves the conditions of heat exchange during work and correspondingly signalizes its "facility". As a result, the energy cost of the work is reduced and the currents of muscle action are diminished As can be seen, muscular activity accompanied by warming from within is associated with change in the sensitivity of the organism to temperature from without. Under the influence of temperature the excitability of the brain centers are reduced during the muscular work session, which can be seen from the decrease in the extent of the suppresion of the α-rhythm in the electroencephalogram during the work session. This, in its turn, is accompanied by changes in the excitability of the muscular system and is reflected in the electromyogram. This brings to mind the genetic kinship of oscillations of muscle action currents and the biocurrents of the brain for man. Göpfert and Stufler tend toward this concept, observing the characteristic periodic rhythm of the electrical potentials of muscle in man, coinciding with the Berger rhythm, in stages preceding the onset of shivering during cooling. There are also indications (3) in the literature that correlative changes in the electroencephalogram and electrical impulsation in muscle fibers are realized with the participation of thermoreceptive structures of the hypothalamus region (investigations on animals). In this connection, the integral reaction of the organism during muscular activity, occurring under given temperature conditions, is provided for, it can be reasoned, by a constellation of cortical formations, heat controlled centers of the hypothalamus, and motor centers of the brain and the spinal column. Thus, during the period of muscular activity, very complex interactions of the central and peripheral

formations appear, participating in the control of heat in the organism.

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MODE OF PROTEIN RESTORATION IN THE CEREBRAL CORTEX AS DEPENDENT ON ITS FUNCTIONAL CONDITION

/Following is the translation of an article by E. I. Shnyak in the Russian-language publication Doklady Akademii Nauk SSSR (Reports of the Academy of Sciences USSR), Vol 146, No 3, 1962, pages 734-736./

(Presented by the Academician V. N. Chernigovskiy on 13 April 1962.)

The author became interested in the problem of the biochemical phenomena which lie at the basis of the exhaustion of nerve cells.

V. S. Shapot (1) suggested that exhaustion of the physiological system is related to the emergence in the system of effective elements of competitive relationships among the processes of plastic and specific functional metabolism for the utilization of the total energy source -- ATP, where during extreme and prolonged work energy is provided for functional metabolism to the detriment of plastic synthesis. This must also lead to the debilitation of the vitality of the functioning structures.

These considerations have served as an approach toward setting up model experiments with large cytoplasmatic granules of the cortical substance of the kidneys. By means of an addition to the enzyme system, counteracting the terminal phosphate group of the ATP by the phosphorylation of sugar, a sharp -- two-fold -- retardation in the restoration of proteins and phospholipids was effected, in spite of the increase in respiration and phosphorylation (2).

Somewhat recently, using the isolated heart of the frog it was shown that in the exhaustion of the cardiac muscle as a result of prolonged isometric contraction, a statistically reliable decrease in the rate of inclusion of radioactive aminoacid in the protein by 30 % was observed, which can not be attributed to weakening of respiration and phosphorylation, since the restoration of the ATP phosphorus was not inhibited (3).

It was natural to test the possibility of the appearance of

the postulated regularity in a more complex case, specifically by studying plastic synthesis in the brain under various functional states of the central nervous system for the entire organism.

In the present study, with the use of radioactive methionine restoration of the protein of the cerebral hemisphere cortex was studied during an exhausting excitation. The experiments were carried out on white rats of both sexes ranging in weight from 40 to 130 g.

The methionine was dissolved in a physiological solution on the basis of 5×10^{-5} imp/min per 0.1 ml and was administered subarachnoidally, which assisted in a more rapid inclusion in cerebral protein than possible for subcutaneous administration, and permitted the tracing of protein restoration in the cortex for brief intervals of time.

After a 30-minute exposure to S^{35} methionine the rat was sacrificed by decapitation, its brain was rapidly removed from the skull and washed in a Buchner funnel with the iced physiological solution. Following filter paper drying of the brain, the cortex was separated and pulverized into previously chilled distilled water. The proteins settled by boiling at a small pH of 4.5. We did not use trichloracetic acid in precipitating the proteins due to the fact that the recording of the radioactivity of the nonprotein fraction (as well as for the proteins) then occurred in a fine layer, whose internal absorption could be neglected, as we were convinced by a special confirmatory test.

The time elapsing between removal of the cortex and precipitation of the proteins was not more than 1½ minutes. The precipitate of the proteins was washed with ice-cold acidified water; the washed waters and the initial nonprotein fraction were combined. The protein precipitate was freed from lipids by the usual method and was dissolved in 0.05 N NaOH at a temperature of 50-60°. From the solution obtained samples were removed for quantitative determination of protein (biuret reaction) and radioactivity count on a Belau instrument with an end-window counter.

To eliminate the effect of differences in the administered dose of radioactive tracer and in the weight of the animals in the various experiments, the value of the relative expression of specific protein activity (o. v. u. a. ,otnositel'noye vyrazheniye udel'noy aktivnosti belka).

$$\text{o. v. u. a.} = \frac{\text{specific activity}}{\text{dose (imp.min per wgt of animal in mg)}}$$

Similarly to the protein radioactivity, the radioactivity of the nonprotein fraction of the cerebral cortex, which also is taken per unit protein, was determined.

Comparing the o. v. u. a. of the protein and the nonprotein fraction, it can be concluded whether change in the rate of tracer

inclusion in the protein is a consequence of a change in the rate of protein synthesis or a change in the penetrability of the cerebral membranes.

The state of the exhausting excitation in the rats was attained in the following manner. The animals were previously administered phenamine (0.06 ng per 100 g of body weight), which after 30 minutes created a heightened excitability in the rats (intensified orientational reflex, exophthalmos, and aggressiveness). At this moment a presistent teasing of the rats with a pair of forceps began, in imitation of attempts at seizing the animals. The rats became extremely excited: they adopted a defensive attidude, clicked their teeth, and threw themselves on the forceps and at each other, etc.

At the peak moment of the excitation (after 1-1½ hours following the start of the experiment) the rats were administered the isotope and the teasing was continued an additional 30 minutes. By this time the rats were considerably weakened in their reaction to the irritation, becoming sluggish.

TABLE 1

№ п/п	о. в. у. а. белков			о. в. у. а. небелковой фракции		
	(1)	(2)	(3)	(1)	(2)	(3)
1	3,9; 3,6	3,6; 2,0	6,0; 4,8	18,9	22,6	17,5
2	3,1; 3,1	2,6; 2,4	4,2; 4,8	16,7	15,7	20,6
3	3,8; 3,8	3,2; 2,0	8,0; 4,0	15,4	19,3	27,6
4	3,6; 4,4	3,2	6,4; 9,7	22,5	17,6	23,8
5	2,8; 5,3	2,5	7,1; 8,5	17,1	21,7	17,1
6	2,6; 6,4	2,5	5,6; 5,8	12,7	19,2	12,5
7	4,3; 3,9	1,9	8,6; 9,2	20,6	24,7	11,1
8	3,6; 5,3	2,4	4,8; 5,0	23,7	22,5	18,5
9	4,6; 4,6	1,3	6,3; 8,2	22,7	16,5	10,0
10	5,5; 3,6	2,7	5,5; 6,8	12,0	10,6	17,0
11	3,9; 4,0	2,4	4,2; 7,1	16,2	20,2	27,6
12	5,2; 4,6	1,4	2,2; 6,6	16,7	15,1	32,6
13	3,5; 4,5	1,9	5,9; 8,4	17,0	28,1	21,5
14	3,1; 4,5	2,9	3,6; 8,8	12,0	25,5	17,0
15	4,1; 2,0	2,0	3,6; 10,0	15,0	18,7	18,9
16	4,3; 4,1	1,7	5,5; 7,2	17,1	14,3	17,5
17	2,6; 3,9	2,4	5,2; 6,6	14,1	12,1	25,3

№ п/п	п. у. а. белков			п. у. а. небелковой фракции		
	(1)	(2)	(3)	(1)	(2)	(3)
1	1,2; 1,6	2,1	5,6; 6,8	18,7	12,3	21,0
2	2,5; 1,6	2,0	7,1; 8,9	19,8	16,0	19,8
3	0,8; 1,6	4,0	6,2; 7,6	21,6	21,6	17,3
4	2,5; 3,5	5,6	5,8; 6,6	22,6	22,8	23,0
5	1,1; 1,8	3,2	2,6; 8,4	17,3	18,8	17,9
6	2,1; 1,8	5,1	3,7; 6,8	26,0	13,8	25,0
7	2,3; 4,0	3,2	3,1	13,4	15,3	21,5
8	1,6; 1,7	9,5	8,9	17,3	17,9	20,8
9	1,8; 2,8		7,6	28	19,4	21,1
10	2,5; 2,7		8		15,3	21,0
11	0,6; 4,1		5,9			19,8
12			4,7			
13			4,9			
14		28	53	26	27	25
15	m	3,0±0,3	5,8±0,27	16,6±0,6	18,4±0,9	19,3±0,80
16	t	4,5	6,4	<1	<1	<1
17	p	0,001	0,001	0,3	0,3	0,3

LEGEND: a) No of exp. animals; b) o. v. u. a. for proteins; c) o. v. u. a. for nonprotein fraction.
Remark. (1) - control. (2) exhausting excitation. (3) sleep following exhaustion.

As seen from Table 1, the rate of tracer incorporation in the protein of the cerebral cortex falls off sharply during exhausting excitation. This difference of 30 % is statistically reliable.

Inasmuch as the radioactivity of the nonprotein fraction in the control and in the experimental animals is practically identical, we correctly concluded that substantial changes in the penetrability of the cerebral membranes did not occur, and regarded the difference in tracer incorporation as stemming from a decrease

in the rate of protein synthesis in the cerebral cortex under the conditions of profound exhaustion of the central nervous system.

A similar retardation of protein synthesis in the brain of rats (19 %) was observed by Gaitonde and Richter (4) for electric current irritation of the brain.

Rozengardt and Maslova (5) discovered a marked decrease in the rate of introduction S^{35} methionine into cerebral protein during a period of convulsions caused by the administration of corosole.

In addition, many authors (6-8), during relatively moderate excitation, found a certain acceleration in the restoration of cerebral protein.

In those of our experiments where the isotope was administered at the very outset of the teasing, the subsequent 30-minute irritation did not involve the appearance of signs of exhaustion, and the rate of protein restoration in the cerebral cortex either did not change or increased somewhat.

The next step was an explanation of the question as to how short sleep occurring at the moment of profound exhaustion of the central nervous system affects the rate of protein synthesis of the cerebral cortex. This is all the more interesting in that (as far as we could judge) such sleep resulted in essential changes in the functional state of the experimental animals.

The animals were subjected to prolonged teasing until a state of extreme exhaustion was arrived at (even more profound than in the previous series of experiments, in which the animals ceased entirely to react to the irritation). They could be picked up with unprotected hands without any precautions. When the irritation was terminated, the animals fell into a deep sleep. The conditions favorable to sleep were created -- the compartments were darkened and were heated by a reflector.

After 30-minutes of sleep the animals were transformed. They displayed the usual defensive reaction and the orientational reflex. These symptoms witness to the fact that sleep permotes the restoration of the vitality of the central nervous system.

The determination of the radioactivity of the cerebral cortex proteins of such animals which had been administered the isotope before falling asleep showed that a 30-minute sleep in addition, stimulated the synthesis of cortex proteins: its rate increased by 48 % in comparison with the control and by a substantially higher value in comparison with the original state of exhaustion of the central nervous system.

As revealed by the experiments which will be reported in detail in another place, accelleration of tracer incorporation in the protein of the cerebral cortex during the sleep period correlates with the decrease in the content of residual nitrogen and amino-nitrogen of the free amino acids of the cortex. This fact strengthens the conclusion that protein synthesis occurs here.

Stimulation of the synthesis of cerebral proteins during the

sleep period, as far as we know, is an original discovery. The literature usually contains data on the unchanged or somewhat decreased rate of protein restoration under these conditions.

This deviation, apparently, is explained by our experimental arrangement, in which sleep sets in following the exhaustion of the central nervous system and the original state left its impression on the direction of the changes in the protein metabolism of the brain.

The probability of a similar effect was previously theorrhetically substantiated by V. S. Shapot (1) based on the above indicated considerations of the competative relationships between functional and plastic metabolism. At the moment when sleep inhibition of the central nervous system sets in after the system has been exhausted, the functional activity of the nerve cells is sharply suppressed and the possibilities for switching over the energy which has been built up into the channel of plastic metabolism are created, which must involve an acceleration of the plastic processes in the brain, and in particular -- an acceleration of protein synthesis and increase in vitality.

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